Semi-Automatic Detection of Artificial Terrestrial Targets for Remotely Sensed Image Geo-Referencing

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***Abstract*--- Geo-referencing of remote imagery with high spatial resolution can be achieved using the semi-AUtomatic GEO-referencing (AUGEO) system which is based on artificial terrestrial targets (ATTs) and software AUGEO-2.0 for location and geo-referencing. The aim of this paper is to describe the system and validate it. The ATTs consist of coloured hexagonal tarps 0.25 to 1.0 m in diameter, placed on the ground and geo-referenced. The proposed software works as an add-on of ENVI and was able to locate the ATTs (Isolated or disposed in associated couples) in remote images based on its spectral band specificity.**

To validate the AUGEO system, ATTs were placed on the ground, and remote images were taken from airplanes and unmanned aerial vehicles several times throughout the year at two locations in southern Spain in 2008. Three variables were considered to study ATT detection accuracy: 1) ATT size, 2) ATT colour, and 3) distance between ATTs when they were coupled in pairs. The averaged accuracy for the coupled 1 m red ATT (2.5 m separated) was 95.9%. As the ATT size decreased, the accuracy generally decreased, regardless of the colour of the ATTs. Results from coupled analysis shown that ATT detection increased as the distance between the ATTs decreased. The proposed system required less time than conventional geo-referencing work, and allowed the geo-referencing of images that do not contain recognisable ground control points (GCPs). This also contributed to the site-specific management of agricultural plots through remote sensing, which required high spatial resolution and accurate geo-referenced images.

***Index Terms*--- Geographic Information Systems, image processing, remote sensing, software engineering**

I. Introduction

Prior to the development and proliferation of high spatial resolution technologies, a field site could be correctly located within the imagery using uncorrected GPS locations [1]. Ground-truth sites can be accurately located within high-spatial-resolution imagery (QuickBird and GeoEye-1 satellites, conventional airplanes, Unmanned Aerial Vehicles (UAV)) by using sub-meter Differential Global Positioning Systems (DGPS). However, these images introduce another segment of the error budget due to the geographic geo-referencing between the imagery and the field sites. This problem occurs, for example, in training and validation samples [1].

Precision agriculture uses diverse technologies to apply fertilisers, pesticides or other inputs at variable rates that depend on the needs of the particular small defined area [2], [3]. This approach takes into account the spatial variability of biotic factors (e.g., weeds and pathogens) and abiotic factors (e.g., nutrients and water content). Remote sensing is an important tool in precision agriculture because biotic factors such as weed patches [4], [5] and fertility levels [6] can be mapped. Most applications of remotely sensed imagery in agriculture require a spatial resolution of less than 10 to 15 m. A finer spatial resolution generally leads to a more accurate assessment. Efficient programming of site-specific operations of biotic factors such as mapping weeds typically requires a spatial resolution of 1 m or less [4], [5]. Remotely sensed images with spatial resolutions between 0.25 and 1.0 m are suitable for olive grove characterisation using CLUAS software [7].

Precision agriculture typically requires images with high spatial resolution (pixels < 1 m) and accurate geo-referencing (ideally error < 0.3 to 0.5 m) Remote images often are provided without geographic coordinates, or its geo-referencing accuracy is far below the accuracy that is needed for precision agriculture. Remote imagery taken from UAV flying 50 to 100 m above the ground may have a bright future in precision agriculture [8], but these images are not geo-referenced. Neither are some images provided by commercial companies flying at 1000 or 1500 m. The geo-referenced commercial panchromatic satellite images with 0.6 m spatial resolution such as those from QuickBird Satellite are normally provided with geo-referencing errors of 15 to 20 m [9], [10]. This geo-referencing error is unacceptable for precision agriculture. A geo-referencing error higher than 1 or 2 m is insufficient to establish a site-specific prescription maps for a variable-rates application of fertilisers or pesticides.

Several authors have developed procedures to obtain more accurate image geo-referencing. Pagnutti et al. [11] used ground points for verification and validation (“V&V sites”). Toutin and Chénier [9] suggested that high resolution images should be processed based on ground control points (GCPs) and digital elevation models (DEM) to generate high precision three-dimensional maps. Sui et al. [12] used ground targets and differential global position systems (DGPS) to build weed maps using weed sensors (“weed seeker”). Hughes et al. [13] studied the main causes of positioning errors and their implications for geo-referencing.

The GCPs, also known as “fixed points” or “hard-edge points”, are usually assigned at the corners of structures such as buildings or road intersections, and their coordinates are usually available from geographic information systems developed by local governments. Remote images of some agricultural areas often lack easily recognisable GCPs, regardless of the area covered (e.g., 5 to 250 ha). In these cases, field work must be performed to geo-reference the identifiable GCPs using DGPS with sub-metric precision. Afterwards, the corresponding image of the GCPs must be processed. Field work and image geo-referencing both considerably increase the cost of using remote images in precision agriculture. Moreover, with the development of high spatial resolution imagery, the impact of errors in geographic geo-referencing between imagery and field sites has become apparent. These errors potentially limit the application of these images for classification, especially when the images involve patchy target detection [1]. These authors studied the effect of geo-referencing on the classification accuracy using artificial patchy targets randomly placed over the image area. They concluded that the producer's accuracy of the target classification increased, and the error due to location decreased to zero at a high geo-referencing level. Weber et al. [1] highlight the importance of considering the geo-referencing between the imagery and the field sites in the error budget, especially for studies involving high spatial resolution imagery and patchy target detection.

To our knowledge, no study has been performed to semi-automatically locate the artificial terrestrial targets (ATTs) in the image area when the ATTs have been deliberately placed in the field for geo-referencing. The goal of this paper is to describe the development of a system based on semi-automatic location of geo-referenced ATTs as a previous step for the geo-referencing of remote images. These ATTs are captured in the imagery and automatically recognised using a specific image-processing software called semi-AUtomatic GEO-referencing (AUGEO-2.0). Our specific objectives are as follows: a) to describe the software development; b) to study the recognition of ATTs by the software as a function of the colour and size of the ATT; and c) to determine the detection accuracy of the system based on two paired ATT placed at a defined distance from each other.

II. Material and Methods

A. Locations and remote images

The studies were conducted in the province of Cordoba in Andalusia (Southern Spain). Areas of about 50 ha were selected at the Dehesa (Posadas) and Navajas (StaCruz) farms. The coordinates (Universe Transverse Mercator System, zone 30 North, Datum WGS-84) of the upper left corner of the images were X = 316286 m, Y = 4186492 m; and X = 360871 m Y = 4185419 m for Dehesa and Navajas, respectively. The ground of Dehesa is flat (average slope <1%), and that of Navajas is hilly, with slopes between 2 and 9%. At Navajas and Dehesa, the images were taken by Hifsa-Stereocarto[1] at 08 June 2008 and 15 September 2008 from a turboprop twin-engine airplane CESSNA 421 flying at 1500 m above the ground with a Vexcel camera model UltraCamD. The digital images were obtained with an average scale of 1:10000. These images include colour-RGB and NIR spectral bands (blue: 400-500 nm; green: 500-600 nm; red: 600-700 nm; near infrared: 700-1100 nm), and the spatial resolution was 0.25 m. Images of both locations were also taken on 23 November 2008 by Quantalab[5] from an unmanned aerial vehicle (UAV) at 100 m altitude with a multispectral camera model MCA-6/ Tetracam at 100 m altitude. The UAV provided NIR, R and G spectral bands images with a spatial resolution of 0.25 m. The main land uses were citrus and olive orchards; annual crops such as corn, cotton, wheat, sunflower, broad beans; tilled land; rivers and river-side/ riparian trees; pavement and bare roads; and civil buildings. No navigation data was used to achieve the studies.

The software used to process the images was ENVI 4.6. AUGEO-2.0 was fitted as an add-on of ENVI.

B. Artificial terrestrial targets (ATTs)

The ATTs were hexagonal tarps with diameters of 0.25, 0.50 or 1.0 m (Fig. 1) were screwed into the upper part of a 0.015 m wide and 0.5 m tall metallic support in a horizontal position. The support was placed vertically in the ground at a depth of 0.3 m. The parasol could be unscrewed and folded. The ATTs were placed on the farms before the images were taken and geo-referenced using the DGPS Trimble PRO-XRS6. Each ATT support could be kept at the same point to avoid the need for new DGPS operations for each airborne image taken in the same scenery. The tarp could be any colour that is easily differentiated from the surrounding area (e.g., white, yellow, red or silver). No part of any ATT was placed beneath vegetation or near tall vegetation (> 1m) to avoid shadowing.

In our studies, as later described, the ATTs were placed on the ground as single ATTs or conforming couples of ATTs. In this case each ATT of a couple was distanced from 2.5 to 20 m from the other.

C. Statistics on ATT detection accuracy

For each image location, AUGEO-2.0 was used to locate all the ATTs placed in the imagery (True Positive, TP) and to determine the "false spots" such as wells, cars, etc. that the software do not discriminate from ATTs due to spectral similarities to real ATTs (False Positive, FP). These data was used to obtain the user accuracy.

The user accuracy was calculated as described by [14] as follow:

$$Acc\% = \frac{TP}{TP + FP}100 \qquad (1)$$

D. AUGEO-2.0 software development

1) Image processing requirements: ENVI, IDL and AUGEO-2.0

The Environment for Visualizing Images (ENVI) is a well-known computer program for visualizing and processing images. ENVI is written in Interactive Data Language (IDL), a systematised computer language that can integrate image processes. The AUGEO-2.0 software is written in IDL and was developed as an add-on for ENVI. The AUGEO-2.0 system was developed by the Precision Agriculture Group of the Institute for Sustainable Agriculture, CSIC, Spain [15], [16]; to semi-automatically locate geo-referenced artificial terrestrial targets (ATTs).

The ATTs, which are described above, are captured in the remote images, and AUGEO-2.0 semi-automatically determines the location of the ATTs in the image and incorporates their geographic coordinates into a file. AUGEO-2.0 provides a visualisation of the location of the ATTs in the image as a region of interest (ROI) and an output file that includes the boundaries digital values (BDV) and the geographical coordinates of each ATT. This output file is incorporated in the geo-referencing menu of ENVI (Map → Registration → Select GPS → Image to Map) and the whole image is geo-referenced.

2) Overview of the operational procedure

AUGEO-2.0 software identifies ATTs in remote images. The coloured ATTs are distinguished from the surrounding area and exhibit different band multispectral digital values than the main land uses. AUGEO-2.0 processing algorithms locate the ATTs in the image, estimate their geometrical centres and record them in the output data file.

Boundary of Digital Values (BDV) estimation.

To discriminate ATTs from land uses, AUGEO-2.0 determines the ATTs BDV of each multispectral band (independent of the number of them) for each colour of the ATTs used. This information is incorporated into the main interfaces by drawing ROIs for 2 to 3 coloured ATT on the image. The corresponding BDV of each band are automatically incorporated into the main interface. The AUGEO-2.0 then automatically locates the rest of the image targets by eliminating any pixel that does not fit the BDV of each band.

AUGEO-2.0 options and parameters

The add-on *AUGEO-2.0* consists of the following three options or submenus: *Find Single ATT*, *Find Coupled ATT* and *Make .PTS file* (later described).

-- *Find Single ATTs* is the submenu used to locate the ATTs of only one colour in an image. This function generates two output files, one of which is the *Make .PTS file*. To use this function, the five parameters must be inserted in the main interface.

-- *Find Couple ATTs* option is used to locate couples of ATTs placed in the terrain. Each couple is made up of two targets with different colours (e.g., red and white) 4 to 5 m apart from each other (Fig. 1 and 3). Processing the coupled ATTs location involves two consecutive *Find Single ATTs* location searches, one for each colour. The AUGEO-2.0 discards every centre without a complementary ATT at the defined distance. The *Find Couple ATTs* option searches the definition of the BDV for each of the coloured targets.

--*Make PTS File* option combines the *output file* generated by the previous options with the *ATTs GPS coordinates file*. The *PTS file* can be opened by the geo-referencing menu of ENVI to automatically geo-reference the image.

E. Effect of ATT colour and size on single ATTs recognition

This study was conducted with the aerial images taken at Navajas and Dehesa in June and September 2008. The ATTs of different colours (white, yellow, red and silver) and sizes (0.25 m, 0.50 m and 1 m diameter) were displayed on the ground. Four colours were present for each size combination unless otherwise stated. Each ATT was geo-referenced with a differential GPS. AUGEO-2.0 was used to locate all the ATTs placed in the imagery and to determine the “false spots”. The NIR, R and G bands of the spectrum where used to ATTs detection in every study.

The AUGEO system efficacy was determined by the accuracy of the User Accuracy Table. This accuracy is the percentage of detected ATTs over the total number of targets detected by the software.

F. Efficiency of the Coupled ATTs detection

This study was conducted with the UAV images taken at Navajas and Dehesa in November 2008. About twenty-four ATT couples, each consisting of 1 white and 1 red 1-m-diameter target, were placed in every study plot. In each couple, the distance between the white and the red target was about 20 m. The software was used to locate ATTs considering it as isolated or coupled ones and the number of false spots was determined. The AUGEO system efficacy in both cases is expressed by the user accuracy table.

G. Effect of the distance between the ATTs in each couple on the detection accuracy

Using the same UAV images of Navajas and Dehesa previously described, a simulation study was conducted to determine the effect of the ATTs distance in a couple on the detection accuracy. The original images, in which the ATTs of each couple were about 20 m from each other, were transformed consecutively to identical images in which the ATTs of each couple were located at 2.5, 5, 10, 15 and 20 m. The image transformations were performed using the ENVI software. Each red target and it corresponding surround pixels were copied at 2.5, 5, 10 or 15 m from the adjacent white target. The software was used to locate ATTs and the number of false spots was determined. The AUGEO system efficacy in both cases is expressed by the user accuracy table as previously described.

III. RESULTS

A. Effect of ATT colour and size on single ATTs recognition

The user accuracy for single ATTs recognition efficacy is shown in Table 1. All ATTs placed on the ground were located by the software system regardless of the ATT colour, size or location. However, the target detection accuracy varied considerably with the size and colour of the ATT and by location. For example, the percentage of accuracy of the red 1 m ATT was 68.18%. As the size of the ATT decreased, the detection accuracy decreased, regardless of the colour. The percentage of accuracy was 68.1, 0.03 and 0.01% for the 1.0, 0.5 and 0.25 m red ATT, respectively. Generally, silver ATTs were poorly discriminated due to have similar spectrum with the surrounding (data not shown).

B. Efficiency of the Single/Coupled ATTs detection

The percentage of accuracy of the coupled target location was always higher than that of the single target location, regardless of the colour of the target. For example, the accuracy was 26.2% for the single red ATTs and 50.00 for the location of a red ATT in a couple (Table 2). The red ATT were slightly more likely to be detected than the white ones. An intermediate value of 44.9% was obtained with the coupled ATTs location. This value indicates the detection of one false spot for every true ATT and is almost a practical result. The detection of one false spot for each true ATT could be due to the distance between the two ATTs of each couple (20 m in this study). This long distance required the submenu to evaluate a considerable area surrounding each true ATT detected. To reduce this surrounding area, the distance between ATTs must be shortened.

C. Effect of the distance between the ATT in each couple on the detection accuracy

The percentage of accuracy was lower using the Single ATTs location than with any treatment considered using the coupled ATTs location (Table 2). As the distance between ATTs decreased, the detection accuracy consistently increased (Table 3). The percentage of accuracy values were 50.0, 57.3, 64.3, 83.9, and 95.9 for the red ATTs and 39.8, 53.4, 59.4, 74.6, and 94.0 for the white ATTs separated by 20.0, 15.0, 10.0, 5.0 and 2.5 m from its corresponding target (Table 3). To obtain a high level of correct ATTs detection (< 1 false ATT detected out of 25 true ATTs), a couple of ATTs, each of a different colour, should be placed at a short distance (e.g., 2.5 m). The high values of accuracy obtained enhance the proposed system for practical uses.

IV. DISCUSSION

A. Effect of ATT colour and size on single target recognition

The adequacy of the target size is related to the spatial resolution of the image. In our studies, the ATT that were 1 m in size were adequate for analysing the remote images of 0.25 m pixel. The ATT that are similar in size to the spatial resolution of the image (e.g., 025 m ATT in images of 0.25 m of pixel) are not easily differentiated because of the diffuse radiation of the adjacent pixels surrounding the ATT. This radiation alters the effect of the colour and the corresponding BDV of its spectral bands. This is according to Lechner [17] and Hengl [18], who concluded that an object must be at least 4 times the pixel size to be easily recognised in a remote image.

The studied colours show similar results at a same ATT size. But the results may vary with the land uses present in the image. The Mediterranean agricultural landscape where these images were taken include white building roofs, white painted wells, red flowers (e.g., *Nerium oleander*) in the spring and summer, resulting in false white and red spots. In the summer and autumn, this landscape includes the yellowish colour of winter wheat stubble, increasing the false yellow spots.

The proposed software used as single target detection was used to detect a high number of false targets. Because an ROI is drawn around each detected target, false targets can be eliminated by visual inspection of the image. This operation is achieved using the ROI menu of ENVI. This menu localises all of the ROI/ false targets. The coupled ATTs recognition avoids the visual elimination of false targets, as previously described.

B. Efficiency of the Single/Coupled ATTs detection

The detection accuracy consistently increases when a couple of different-coloured ATTs is used instead of a single target. The Couple ATTs system avoids the need to eliminate false ATTs by visual inspection of the image. Therefore, the Couple ATT system is highly automated.

C. Effect of the distance between the ATT in each couple on the Find Couple ATT efficiency

To obtain a high level of target detection, a couple of ATTs must be established in the terrain, each of the ATT should be a different colour, and the ATT should be a short distance away from each other (2 to 3 m between the ATT outer parts). The coupled target location should be used to provide high detection accuracy values.

The proposed system requires less time to define and locate GCPs than manual methods. The system also allows the images of areas to be geo-referenced without requiring GCPs for verification and validation. Field operations using the proposed system involve only placing the tarps of the ATTs over their metallic supports and geo-referencing the ATTs before the remote image is taken. These operations can be further simplified if the metallic supports of the ATT are placed in permanent positions and only need to be geo-referenced the first time they are used.

This system is a useful system for definition and location of GCPs as a previous step in the geo-referencing process, particularly in areas with poorly defined ground hard points for verification and validation. This is also useful for geo-referencing images with consistent positional errors. Site-specific agriculture operations can be defined through the system using through remote sensing because they require high spatial resolution images (i.e., pixel <0.1 to 1.0 m) and accurate geo-referencing (i.e., positional error <0.1 to 0.5 m). After the fulfilment of these requirements, each precision prescription treatment can be applied to the corresponding correct area.

V. CONCLUSIONS

An original semi-automatic system called AUGEO has been developed to geo-referencing remote images. This system is made up of artificial terrestrial targets (ATTs) and a software named AUGEO-2.0. ATTs are tarps of about 1 m diameter, geo-referenced and captured in the remote image. The colour of the ATTs must differ from that of the nearby land uses and therefore should be chosen based on the landscape and season. An essential part of the AUGEO system is the proposed software, which works as an add-on of ENVI. This software has been designed to locate the ATTs in the image and incorporate their corresponding coordinates into the map registration menu of ENVI for image geo-referencing and geo-referencing. AUGEO-2.0 is a very efficient system for locating ATTs, particularly if the ATTs are placed in the terrain in couples of targets that are of different colours and at a short distance from each other (2 to 3 m).

AUGEO is a useful system for geo-referencing remote images, particularly in areas with poorly defined GCPs for verification and validation. It can also be used to geo-referencing images with consistent positional errors. AUGEO system requires considerably less time than conventional geo-referencing field work with complementary computer/ office work and allows geo-referencing of images of areas without easily recognisable GCPs.

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